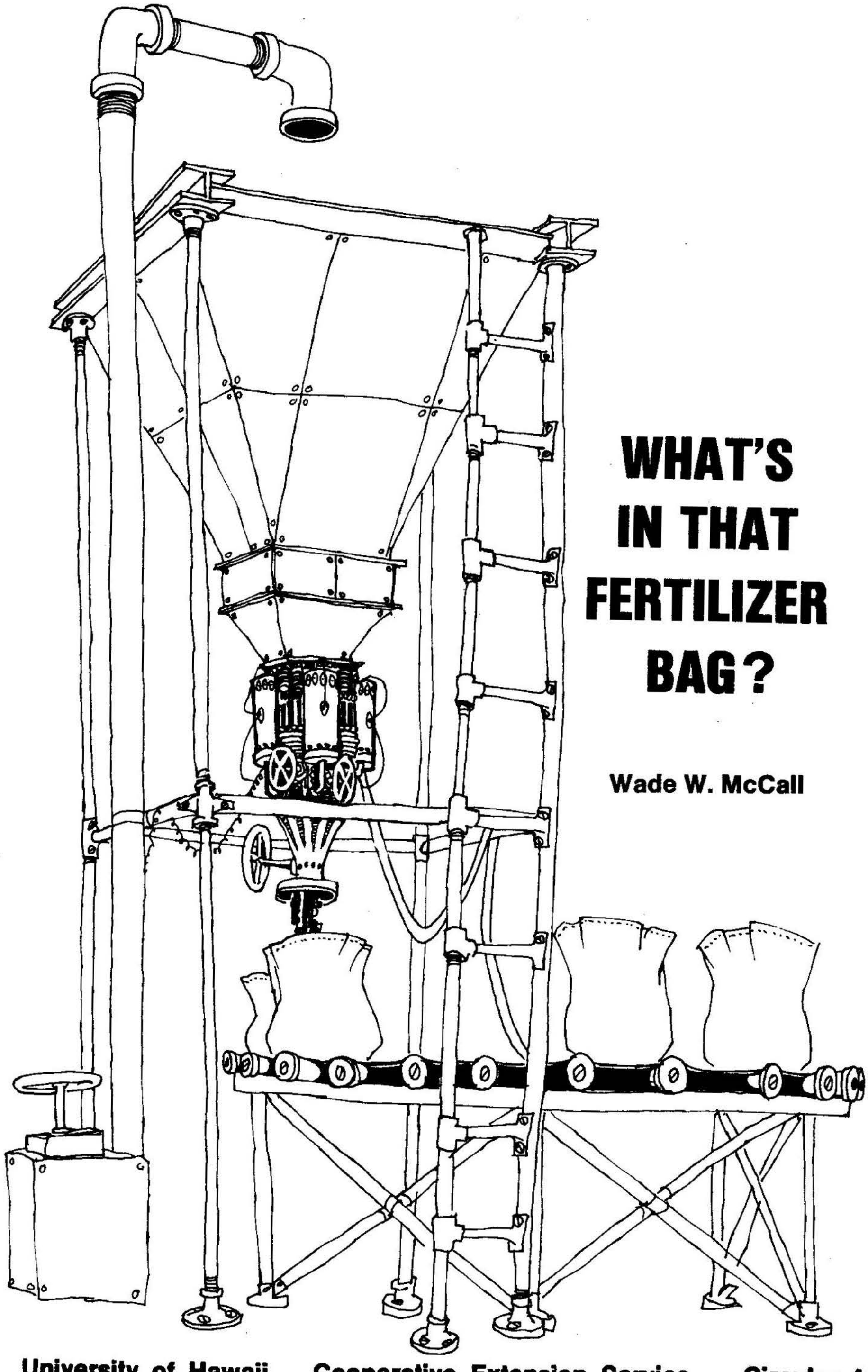

WHAT'S IN THAT FERTILIZER BAG?

Wade W. McCall

University of Hawaii Cooperative Extension Service Circular 441

WHAT'S IN THAT FERTILIZER BAG?

Wade W. McCall
Soil Management Specialist

Each bag or package of fertilizer contains chemical compounds that contain one or more elements essential for plant growth. The chemicals contained in fertilizers, which are absorbed by plants, are known as plant nutrients.[1] Sixteen elements are recognized as essential for plant growth. These are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B), molybdenum (Mo), and chlorine (C1).

Nitrogen, phosphorus, and potassium are known as the macro (major or primary) plant nutrients. Calcium, magnesium, and sulfur are known as the semi-macro (secondary) plant nutrients, and sulfur known as micro (minor or trace) plant nutrients. This classification is based upon the proportion of these essential elements normally found in plants. In fertilizers, nitrogen, phosphorus, and potassium are known as the primary plant foods; all others are known as the secondary plant foods.

Sodium, silicon, and other elements benefit plant growth, but these are not considered absolutely essential at the present time. As methods of analysis and techniques of experimentation are refined, however, these and other elements may be shown to be essential for the growth

[1]Nutrients are often referred to as "plant foods" by the fertilizer industry.

of plants. They would be then added to the list of nutrients essential for plant growth and would be an important component of fertilizers to use in deficient soils. Carbon, hydrogen, and oxygen, comprising more than 90 percent of plant tissue, are obtained from air and water. Their presence in fertilizer should not be considered when determining the supply of plants nutrients contained in a fertilizer. The other nutrients are usually obtained from the soil, but when they are deficient in the soil, they must be added for good plant growth. Materials containing these plant nutrient elements are known as as fertilizers.

Fertilizer Materials

Plants cannot utilize plant nutrients in their elemental forms. Nitrogen is a relatively inert gas; phosphorus is a solid that bursts into flame when exposed to air; potassium is a metal that reacts violently with water; others are relatively inert materials. To be available to plants, these elements must be chemically combined with other elements to form basic compounds. Because of this, the actual amount of plant nutrients in a fertilizer is only a portion of the total weight.

Basic chemicals used to supply plant nutrients are called fertilizer materials, plant food carriers, or "straight" materials. Usually they contain only one plant nutrient element, although some may contain more than one and some may contain one element in two different chemical forms. So that the plant receives all of the needed elements at the same time, two or more of these basic compounds may be combined either chemically or physically to produce "mixed" fertilizers. These are also known as manufactured fertilizers or commercial fertilizer.[2]

Table 1 lists some of the fertilizer materials commonly available for fertilizer use and gives some of their characteristics.

Fertilizer Analysis

A fertilizer containing one or more of the three major plant food elements nitrogen, phosphorus, and potassium is designated by a numbering system that states the percentage of each element in the mixture or compound. These figures are the guaranteed analysis or "grade" of the fertilizer. This numbering system is universally used for mixed fertilizers but it may also be used for "straight" materials.

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[2]Technically, any fertilizer that enters into commerce is a commercial fertilizer. However, in common usage mixed fertilizers are referred to as "commercial fertilizers."

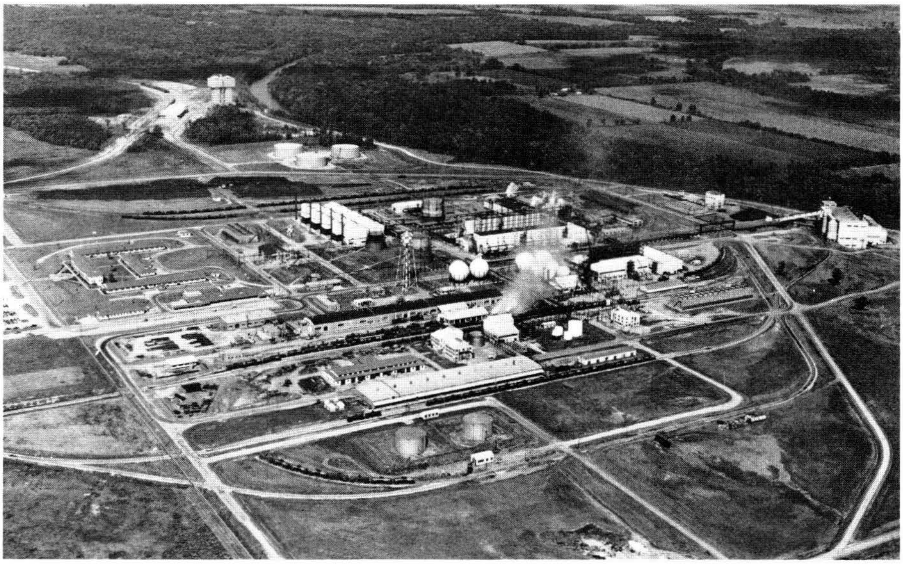
Present practice is to show three figures such as 10–10–10, 16–8–8, 10-10-5, etc., in the guaranteed analysis. An 80-pound bag of 10-10-10 contains 8 pounds of nitrogen, 8 pounds of avaliable phosphoric acid, and 8 pounds of water-soluble potash. The first figure always indicates the percentage of nitrogen (N); the second the percentage of the available phosphoric acid (P_2O_5); and the third, the percentage of water-soluble potash (K_2O). These constitute the available primary plant nutrients.

Nitrogen

The percentage of nitrogen contained in the fertilizer is always stated as the elemental form. However, the plant utilizes nitrogen in the nitrate (NO_3^-) or the ammonium (NH_4^+) form. Fertilizers may contain nitrogen in these available forms, but they may also contain nitrogen in water-soluble or water-insoluble organic forms. The slowly soluble nitrogen materials are one or more of the above forms that have been treated to reduce the rate of notrogen release for plant growth.

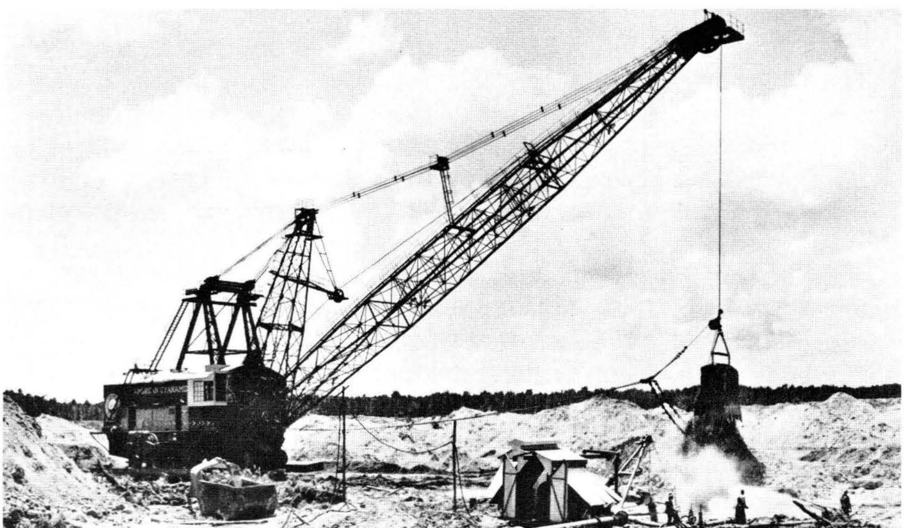
The nitrate form of nitrogen is water soluble and readily available for plant uptake. Because of its negative charge, it usually is not absorbed on the surface of soil particles in the exchange complex of the soil. All other forms of nitrogen may be converted to the nitrate form by microbiological processes if soil conditions are favorable.

Most ammonium forms of nitrogen are water soluble; however, this form of nitrogen is often absorbed by plants more slowly than the nitrate form. The ammonium form of nitrogen has an electrostatic positive charge (NH_4^+) which is readily attracted (absorbed) to the negatively charged surface of the soil particles in the exchange complex of the soil; this reduces leaching losses. Many soils in Hawaii (those that are highly weathered and very acid, the sandy soils, and the slightly weathered soil materials) have little negative charge; this means they have very little exchange capacity so that positively charged ions such as the ammonium (NH_4^+) ion are adsorbed in small amounts. On such soils (as along the Hilo-Hamakua coast of the island of Hawaii) even ammonium fertilizers should be applied frequently in small amounts to pevent an excess of leaching losses. Plants may absorb the ammonium form directly from the soil particles or from the soil solution. This ammonium form remains on the soil particle until absorbed by the plant or until converted to the nitrate form by microbiological action. It is a form of nitrogen more readily absorbed by plants that are naturally adapted to strongly acid or poorly drained soils.



Photograph courtesy Spencer Chemical Co.

Figure 1. Most of the nitrogen contained in fertilizers is fixed from the atmosphere by combining with hydrogen at elevated temperature and pressure in chemical plants such as this.



Photograph courtesy American Cyanamid Co.

Figure 2. Phosphate rock is mined by using huge draglines such as this one in a Florida phosphate mine.

Water-soluble organic sources of nitrogen are rapidly converted to the ammonium form in soils. For this reason it should be considered the same as ammonium nitrogen.

The water-insoluble organic form of nitrogen is derived mainly from natural organic sources such as tankage, hoof and horn meal, fish scrap, sewage sludge, etc. Some come from water-soluble organic sources of nitrogen which have been specially treated to reduce their water solubility. This form of nitrogen has a high resistance to leaching and is less likely to "burn" or damage the plant when applied to the soil. The rate at which the water-insoluble organic nitrogen from different materials becomes available varies widely. The water-insoluble organic nitrogen is very expensive because it is derived from materials with relatively low nitrogen content and because the fertilizer industry must compete with the feed industry for the materials. It is expensive in another way also since, on the average, only about one-third of this form of nitrogen, as now used in fertilizers in Hawaii, is available to the crop to which it is applied.

The ammonium form of nitrogen and the water-soluble organic forms of nitrogen are often combined with or coated with other materials to reduce their rate of availability to plants. This reduces leaching losses and extends the period during which they are available to plants, but it also increases the cost of the nitrogen. These materials are generally valuable for special crops where long-term availability of nitrogen justifies the increased cost.

Phosphorus

Phosphorus is guaranteed as the hypothetical oxide equivalent form.

"Available phosphoric acid"(P_2O_5) is the term used for the oxide form of phosphorus.[3] It may also be called "available phosphate," "phosphoric oxide," or "phosphoric anhydride." This phosphorus is the amount available to the plant. Most of it is water soluble, but part will be soluble in citrate acid or other weak acids. Since the soil solution is generally slightly acidic, the citrate soluble form is considered available for plant use. Present in the fertilizer may be some insolu-

[3]Common practice is to guarantee phosphorous as the oxide equivalent. Presently, attempts are being made by agronomists and others to change the system to guarantee in the elemental form. Most information currently being published is based on the elemental system. This system eliminates confusion in terminology, since no fertilizer actually contains phosphoric acid or P_20_5. However, current terminology is used in this publication for informational purposes.

ble phosphoric acid, a form that is more slowly available to plants. Over a long period in strongly acid soils, however, it does provide phosphorus for plant growth. Most guaranteed analyses do not include this form of phosphorus, but some do.

Potassium

Potassium is guaranteed as the oxide equivalent. "Potash" (K_2O) is the term used for the oxide equivalent of potassium. It may also be called "potassium oxide." Many guaranteed analyses state the potash as water-soluble potash to indicate that it is readily available to the plant. Table 2 gives the scales to use in converting available phosphoric acid (P_2O_5) and water-soluble potash (K_2O) to the elemental P,K equivalents.[4]

Other Plant Nutrients

Calcium, magnesium, and sulfur are generally known as the secondary plant foods to distinguish them from the primary plant foods nitrogen, phosphorus, and potassium. These secondary elements are often present in a fertilizer as a part of the carriers of the primary plant nutrients. Calcium is commonly found in superphosphate, a common carrier for phosphorus. Sulfur is found in ammonium sulfate, a carrier of nitrogen and potassium sulfate, which is in turn, a carrier of potassium. Iron, zinc, copper, manganese, molybdenum, and/or chlorine are often found as "impurities" in carriers for nitrogen, phosphorus, or potassium. Their presence in the fertilizer often is valuable for plant growth, but the amount present in the fertilizer often is not guaranteed by the manufacturer. However, when guaranteed present in the fertilizer, they are stated as the elemental form.

Types of Fertilizer

Fertilizers may be liquids, suspensions, or solids (dry). One material (anhydrous ammonia containing 82% N) is a liquid when stored under pressure but it becomes a gas when used. Suspensions or slurries differ from liquids in that all of the materials are not dissolved but are kept in suspension by agitation and suspension agents. Several analyses or kinds of fertilizers are manufactured as these three types. When the same form of a plant nutrient is applied to the soil in the same manner, whether in solution, suspension or solid, similar results should be obtained since soils contain far more water, even when apparently dry, than can be applied with the fertilizer—except when the fertilizer is applied in irrigation water.

[4]See inside back cover for a pocket-sized Fertilizer Conversion Scale.

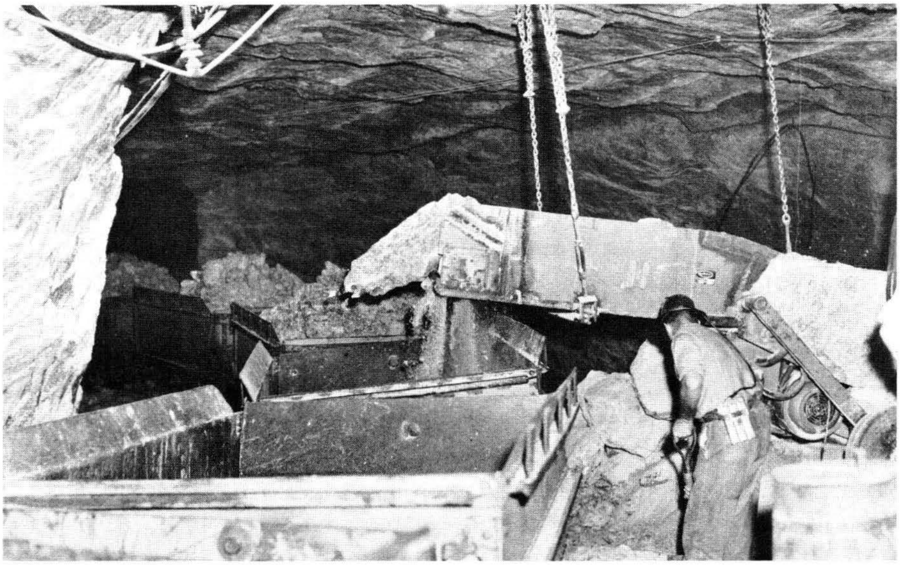
Sources of Fertilizer Materials

Fertilizer materials come from many different sources. Nitrogen materials are produced from nitrogen in the air that is "fixed" by being combined with hydrogen at elevated temperature and pressure. Nitrogen materials are also obtained as a by-product of the coking of coal or of the food and fiber industries. Many of the "by-product" nitrogen materials from the food and fiber industries are used as feeds for livestock and are very expensive sources for fertilizer. Some nitrogen materials are produced from naturally occurring deposits but are unimportant in the fertilizer industry except in local areas.

Many of the sources of nitrogen listed in Table 1 are not available in Hawaii. Anhydrous ammonia is the product of direct fixation of nitrogen from the air. However, it must be stored and handled under pressure (82 pounds per square inch) to be maintained as a liquid for handling; when the pressure is released it becomes a gas. Equipment for shipping and handling anhydrous ammonia is so expensive that none is imported into Hawaii. Ammonium nitrate, which contains both the ammonium and nitrate sources, is used extensively as a source of nitrogen. It is really an excellent source of nitrogen, but other than the nuclear materials, it is the principal source of explosives. Many serious explosions have occurred from its use so that its importation into Hawaii is limited by law. Ammonium nitrate may be imported as a nitrogen solution. The cost of the nitrogen in solution is high, so ammonium nitrate solution cannot compete economically with many other sources, however, it is used on pineapple in Hawaii.

Urea, imported primarily from California and Canada, and ammonium sulfate, imported primarily from California, are the major sources of nitrogen used in Hawaii. Monoammonium phosphate and diammonium phosphate, primarily from California and Idaho; potassium nitrate, primarily from Germany; calcium nitrate, from Norway; and natural organic sources such as tankage, hoof and horn meal, etc., from various sources are other sources of nitrogen used in Hawaii. In addition, large quantities of cattle manure from dairies and feed lots, chicken manure from egg and broiler operations, and digested sewage sludge from City and County sewage disposal plants are available but are used only to a limited extent as fertilizer materials.

All fertilizer materials are imported from the most economical sources available. For this reason, materials may be obtained from one source and then later from another source, depending upon market conditions at the time of purchase.



Photograph courtesy American Potash Co.

Figure 3. Most potassium contained in fertilizers is produced from potash salts mined underground.

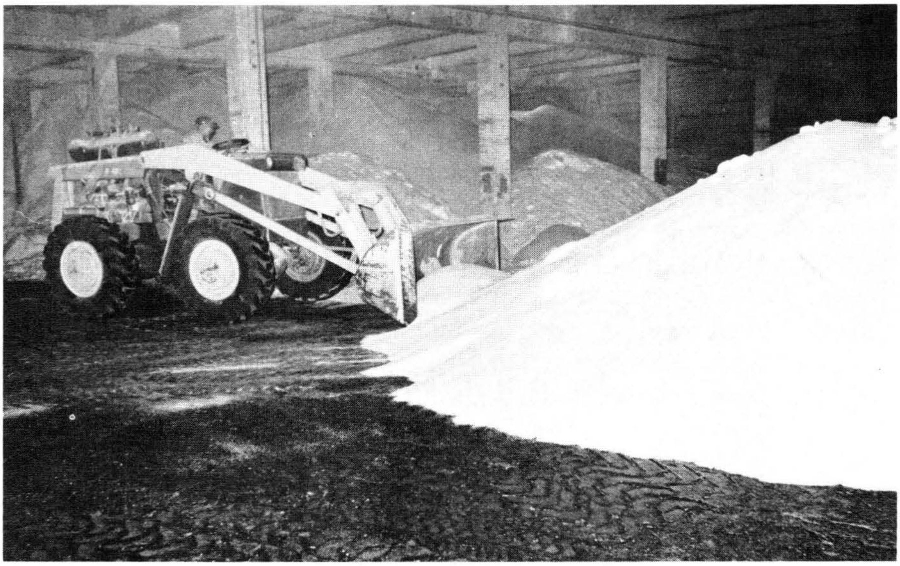


Figure 4. Fertilizers are stored in bulk until ready for use. They are then moved from storage with these front hopper tractors. The materials are dumped into elevators, ready for use in the formulation and batching process.

The phosphorus materials are produced from phosphate rock mined from various deposit throughout the world. The phosphorus sources used in Hawaii are primarily mined in Idaho. The phosphate rock is treated in various ways to make the phosphorus more available. Ordinary superphosphate, primarily from California, is made by treating phosphate rock with sulfuric acid to produce monocalcium phosphate and calcium sulfate. Treble superphosphate, primarily from Idaho, is made by treating the phosphate rock with phosphoric acid. Nitric phosphates (20–20–0 and 15–30–0), primarily from California, are made by treating the phosphate rock with nitric acid. They are not a common source for use as "straight" material but is a constituent of many mixed fertilizers. The phosphate rock must be ground to a fine powder before treatment with an acid to facilitate the conversion of the phosphorus to a more available form. Ground phosphate rock also from Florida or Idaho, may be applied directly to the soil as a fertilizer material; however, best results are obtained when used on acid soils and with plants that have an extensive root system and a long growing season, such as sugar cane. Phosphate rock may be heat-treated to increase the availability of the phosphorus; however, this method has not become commercially important.

Potassium fertilizers are produced from brine lakes where the brine is evaporated to produce potassium chloride (muriate of potash containing 60% to 62% K_2O). Searles Lake in the San Bernadino Mountains of California and Salduro Salt Marsh near Wendover, Utah, are the major brine sources of potash salts in the U.S. Most of the potassium chloride, potassium sulfate, and potassium magnesium sulfate are produced from underground salt deposits. Commercial deposits of potassium salts are mined in New Mexico and Utah in the United States, in Saskatchewan in Canada, and in Germany, France, Spain, Poland and Russia in Europe. These salts are mined and concentrated by refining to produce the fertilizer materials. The major potassium fertilizers used in Hawaii are potassium chloride from California, potassium sulfate from California, potassium magnesium sulfate from New Mexico, and potassium nitrate from Germany.

Most calcium found in fertilizers are part of the carriers for the major elements, especially phosphorus. Calcium may be added to the mixed fertilizer as fillers or conditioners. Calcium is the major constitutent of limestone (ground coral). Since coral is used to maintain desired soil pH levels, calcium is not generally needed in large quantities in fertilizers. In Hawaii, calcium is added as a nutrient to the acid soils used for sugarcane and pineapple production either as calcium silicate, manufactured in Hawaii, or calcium carbonate (ground

Table 1.
Average Composition of Some Fertilizer Materials[1]

MATERIAL	PERCENT PLANT FOOD N	P_2O_5	K_2O	Other % Element	RELATIVE AVAILABILITY[2]	EFFECT OF 100 POUNDS OF MATERIAL ON SOIL[3] Acid	Alkaline
Anhydrous Ammonia	82				quick	148	
Ammonium Nitrate	33.5				rapid	60	
*Ammonium Sulfate	21			24 S	quick	110	
*Ammonium Phosphate (mono)	11	48			quick-mod	75	
*Ammonium Phosphate (di)	18-21	46-53			quick	65-75	
*Ammonium Polyphosphate	15	60			quick	70	
Ammonium Phosphate Sulfate	16	20		15 S	quick	88	
*Ammonium Sulfate-Nitrate	26-30	1		15 S	rapid-quick	65	
Calcium Cyanamid	21			37 Ca	quick		63
*Calcium Nitrate	15.5			21 Ca	rapid		20
*Potassium Nitrate	13-14		44		rapid		23
Sodium Nitrate	16			27 Na	rapid		29
*Urea	46				rapid-quick	84	
*Urea-Formaldehyde	38				slow	68	
Sulfur-Coated Urea	26-40			10-40 S	slow	50-200	
Castor Pomace	5.2	1.8	1.1		slow	5	
Cotton Seed Meal	6	2.5	1.4		slow	10	
*Fish Scrap	6-10	7	1	6 Ca	slow	5	
*Sewage Sludge (Activated)	5-6	2.9	.6		slow	n	n
*Sewage Sludge (Digested)	2-3	1.4	.8		slow	n	n
*Tankage	6-9	1-6	.8	8-11 Ca	slow	16-23	
Tankage, Garbage	2.5	1.5	1.5	4.5 Ca	very slow		7
Blood Dried	12	1.5	.8		mod-slow	23	
Guano, Peru	13	8	2	9 Ca 1.1 S	moderate	13	
Basic Slag		8-12		29 Ca 15 Fe 2.2 Mn	quick		60
*Rock Phosphate		33-35		33 Ca	slow		10
*Superphosphate (single)		18-24		20 Ca 12 S	quick	n	n
*Superphosphate (treble)		45-48		14 Ca 1 S	quick	n	n
*Nitric Phosphate	14-22	10-22		8-10 Ca	quick	29	
Steamed Bone Meal	2.2	27		25 Ca	rapid-quick		25
Phosphoric Acid (liquid)		52-76				110	
*Magnesium Ammonium Phosphate	8	40		12 Mg	slow	n	n
*Potassium Chloride			60-62	47 Cl	quick	n	n
*Potassium Sulfate			50-53	18 S	quick	n	n
*Potassium-Magnesium Sulfate			22-26	11-12 Mg	moderate	n	n
Tobacco Stems	2	.7	6	3.5 Ca	quick		25
*Borax				11.7 B	quick	n	n
*Polybor				20.5 B	quick	n	n
Copper Oxide				75 Cu	quick	n	n
*Copper Sulfate				24.8 Cu 12.8 S	quick	n	n
*Copper Chelate				13 Cu		n	n
*Gyphsum				21 Ca 17 S	slow	n	n
*Iron Chelate				6-12 Fe		n	n
*Iron Sulfate				19.7-34.4 Fe 11.5-13.2 S	quick	n	n
Magnesium Chelate				6 Mg		n	n
Magnesium Oxide				49-60 Mg	quick		220
*Magnesium Sulfate				11-16 Mg	quick	n	n
*Manganese Chelate				12 Mn		n	n
Manganese Oxide				77 Mn	slow	n	n
*Manganese Sulfate				25 Mn 14.5 S	quick	n	n
*Silicate Slag				34.5 Ca 22.2 Si	slow		
*Sodium Molybdate				38 Mo	rapid	n	n
*Zinc Chelate				14.2 Zn		n	n
Zinc Oxide				80 Zn	slow	n	n
*Zinc Sulfate				22-36 Zn 17.6 S	quick	n	n

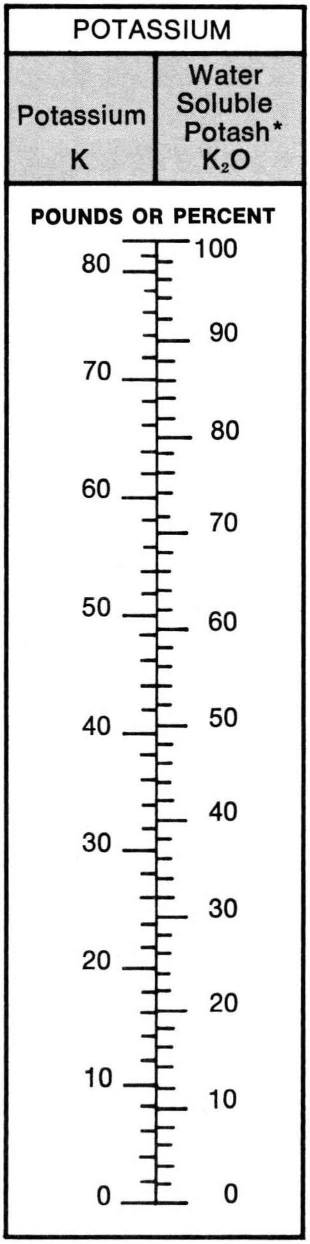
*Material available in Hawaii.

[1]The percentages given in this table are average figures. When buying fertilizer materials, always purchase according to the guaranteed analysis of plant food contained.

[2]Rapid availability means that plants will show a response in less than three days after application. Quick means that plants will show response in three to seven days, moderate in seven to fourteen days and slow requires longer than fourteen days.

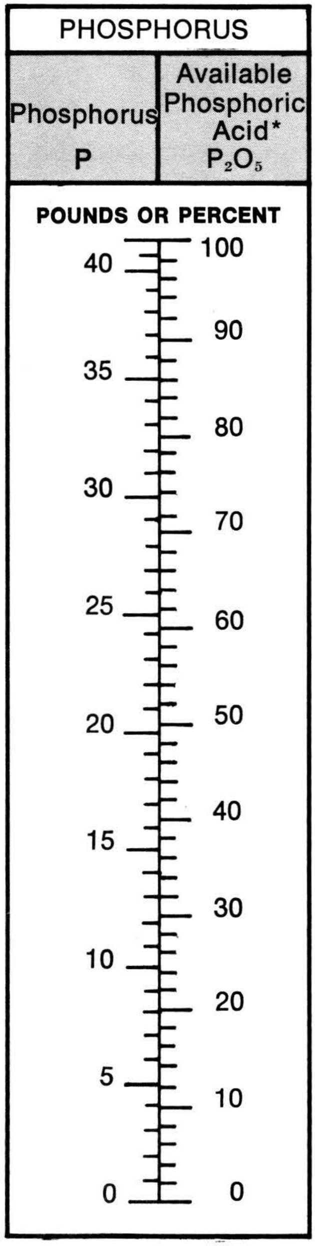
[3]The effect of 100 lbs. of material is given as the calcium carbonate equivalent. Acid requires that amount of calcium carbonate to neutralize the effect and alkaline has the effect as an equal amount of calcium carbonate. The symbol "n" = no effect.

Table 2. Fertilizer Conversion Scales



*Potassium Oxide

$K \times 1.20 = K_2O$
$K_2O \times 0.83 = K$



*Phosphorus Pentoxide

$P \times 2.29 = P_2O_5$
$P_2O_5 \times 0.44 = P$

coral from Hawaii). Other forms that may be used are calcium chloride, (usually as a spray for some vegetable crops), calcium sulfates, calcium chelate, and calicum hydroxide (hydrated lime).

Magnesium may be supplied in the fertilizer as magnesium sulfate (epsom salts, kieserite, Sol-Po-Mag[5]), magnesium oxide, magnesium chelate, or magnesium carbonate (as dolomite limestone). Magnesium sulfate is the most common form. Much of the magnesium used in fertilizers is produced from sea water.

Sulfur in fertilizers generally is found as a constitutent of other materials. However, with the use of more and more treble superphosphate in mixed fertilizers and less ammonium sulfate, sulfur has virtually been eliminated from mixed materials. More and more crops and areas in Hawaii are showing sulfur deficiency so that sulfur is needed in fertilizers to supply this element. Sulfur deficiency has been found on sugarcane, pasture, and some vegetable crops in Hawaii. Sulfur is mined from underground deposits in Texas, Louisiana, and Mexico. It is made into sulfuric acid and used to manufacture many other materials. Most sulfur in fertilizers in Hawaii is in ammonium sulfate or potassium sulfate. Small amounts of elemental sulfur are used also.

Iron, zinc, copper, and manganese are added to fertilizers in the sulfate, the oxide, or the chelate forms. These forms are generally manufactured during the refining of these metals. Ferrous sulfate and zinc sulfate are made in Hawaii from scrap metal and sulfuric acid. Other materials are imported from the mainland United States.

Molybdenum is added to fertilizer in the form of sodium molybdate or molybdic acid. It is mined from deposits in western United States.

Chlorine is found as a constituent of potassium chloride, the most common source of potassium in fertilizers. It is detrimental to crops such as tobacco, potatoes, pineapple, and some vegetables and should be eliminated from fertilizers used for these crops.

Manufacture of Mixed Fertilizers

Mixed fertilizers are manufactured from two or more of the materials containing the essential elements for plant growth. The process of manufacturing consists of many steps, from bringing the materials together and combining them in the proper proportion to the storage or shipping of the finished product.

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[5]Trade name for potassium magnesium sulfate.

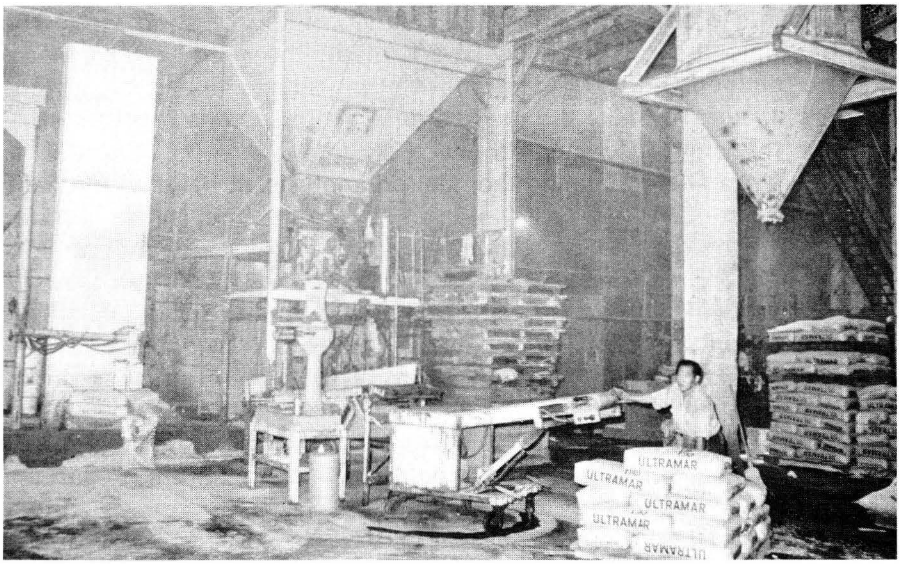


Figure 7. After the operator formulates the fertilizer mixture, it is batched, or mixed, and then elevated into a hopper such as this where it is loaded into valve pack bags for shipment to the customer. The fertilizer is placed on pallets to facilitate handling. Note dust from the mixing operation.

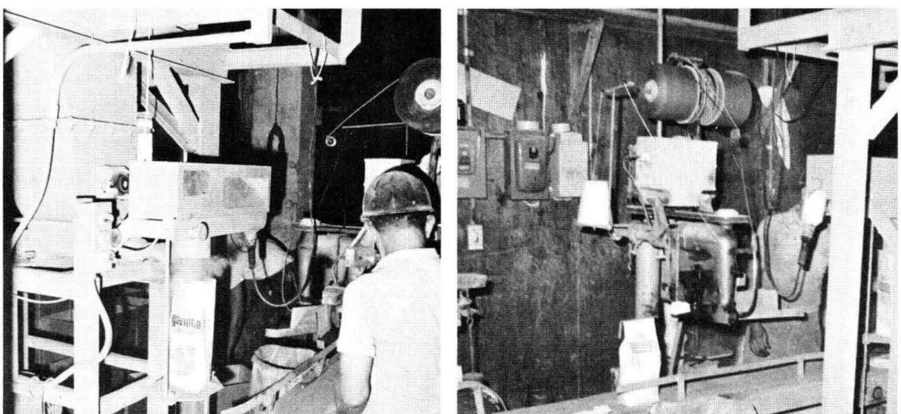


Figure 8. Specialty fertilizers and small containers require special bagging equipment such as this top-loading filler (A) and this sewing machine (B), which closes the bag after filling.

The final product may be in dry, liquid, or suspension form. The dry products are pulverized or granulated. The granulated material may be **blended,** which is the process of physically mixing the various carriers needed to make the desired analysis; or **pelleted,** which is the process of physically and chemically combining the carriers to produce a granule containing the desired analysis. In pelleted fertilizer, each pellet contains the same analysis as the mixture, but in blended materials, each granule is different—one containing nitrogen, one containing phosphorus, and one containing potassium. Both the blended and the pelleted forms are called **granulated** because they consist of large, individual particles or granules that do not "set up" or become hard in storage. They drill easily, do not blow away in the wind as easily as the non-granulated materials. Granulation also reduces fixation of plant nutrients. The granule "isolates" or reduces contact between the soil and the fertilizer, thereby reducing fixation of nutrients in the granule. This is especially important in Hawaii, where most soils have the ability to fix large amounts of phosphorus and immobilize it for plant use. By using granulated materials the phosphorus is maintained in an available form for a longer period of time. Granulation is a special process that involves mixing the dry materials, gaseous materials, and/or liquid materials together to produce a slurry. This slurry is mechanically made into granules and then dried by artificial heat before bagging or storage. Pulverized fertilizers are the powdered forms that have not been granulated.

Manufacturing liquid fertilizers requires a different process but essentially the steps are the same as for manufacturing the dry type. The same is true of suspensions, which require still a different manufacturing process.

Liquid fertilizers are desired by many because they are easy to use. The farmer or grower does not need to handle the material, only use a hose to fill the distributor. Generally, liquids are used in rather limited areas near the manufacturing plant because they have a relatively low analysis as compared to dry or suspension fertilizers. Suspensions may have a higher analysis than liquids, and their major advantage is the same as for liquids—ease of handling. Agitation and special processing are required to suspend the fertilizer.

Fertilizer manufacturers maintain close control over the production of their product. Chemical analysis is performed to maintain the guaranteed analysis within close tolerance of the amount stated. This is done to maintain the reliability of the product and to protect the name of the company.

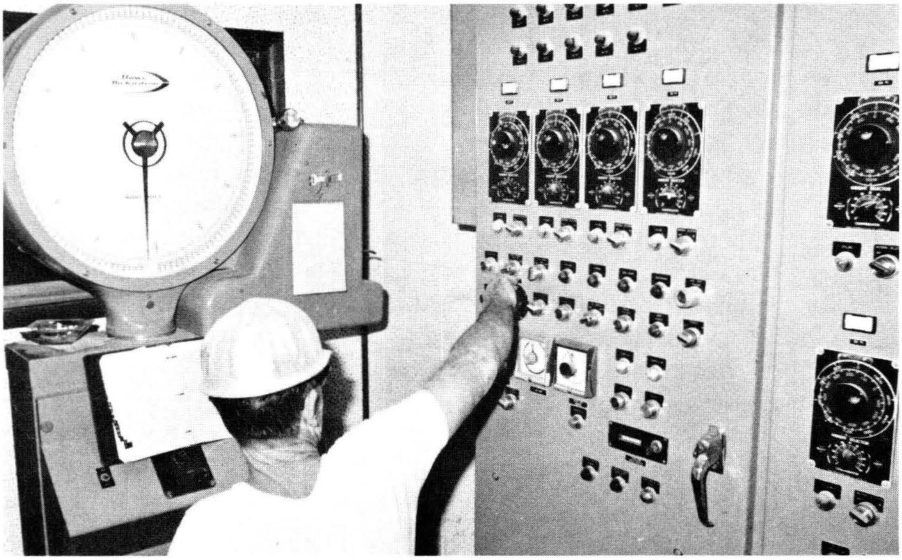
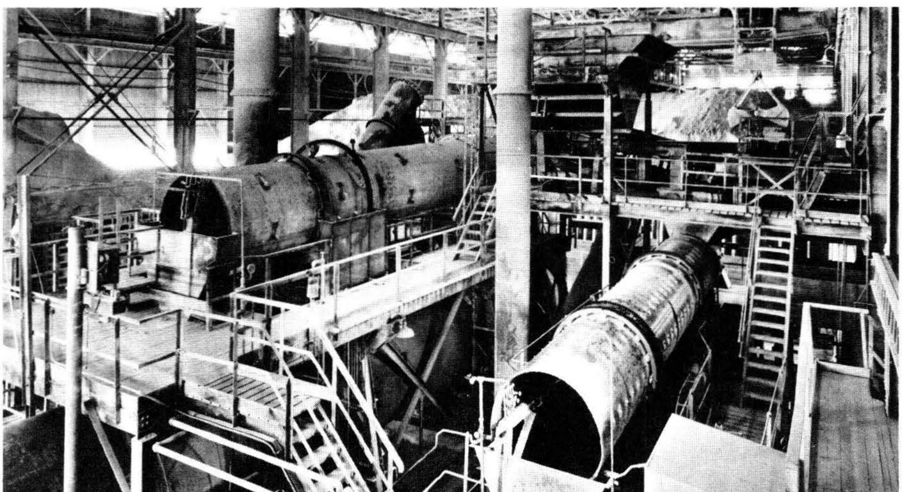
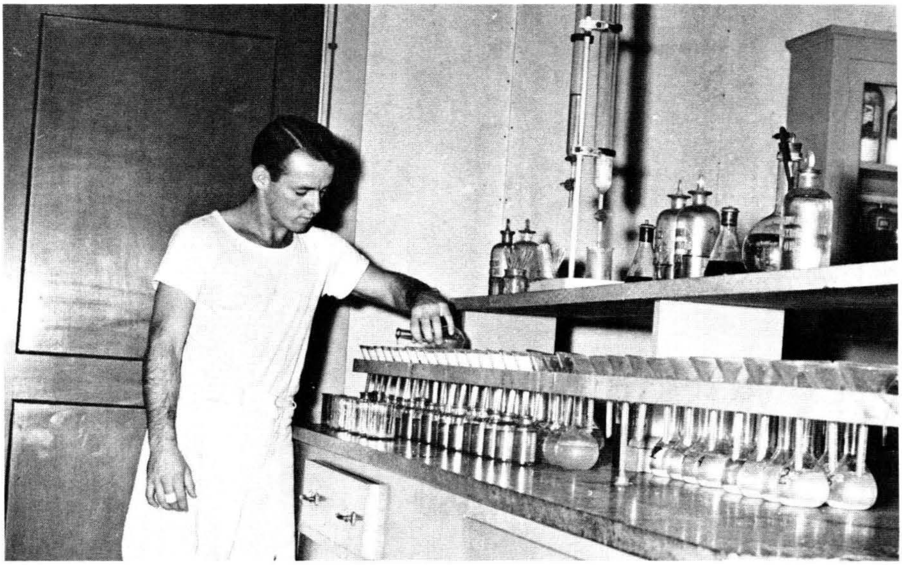


Figure 5. Automated scales and control panel for the formulation of fertilizer mixtures. An operator controls the entire mixing operation from this control panel.



Photograph courtesy Davison Chemical Corp..

Figure 6. Fertilizers are granulated to improve their physical characteristics and to reduce fixation of plant nutrients in the soil. Granulaton is done in plants such as the one shown here.



Photograph courtesy National Plant Food Institute

Figure 9. Fertilizer manufacturers maintain strict quality control of their product by chemical analysis to maintain uniform quality.

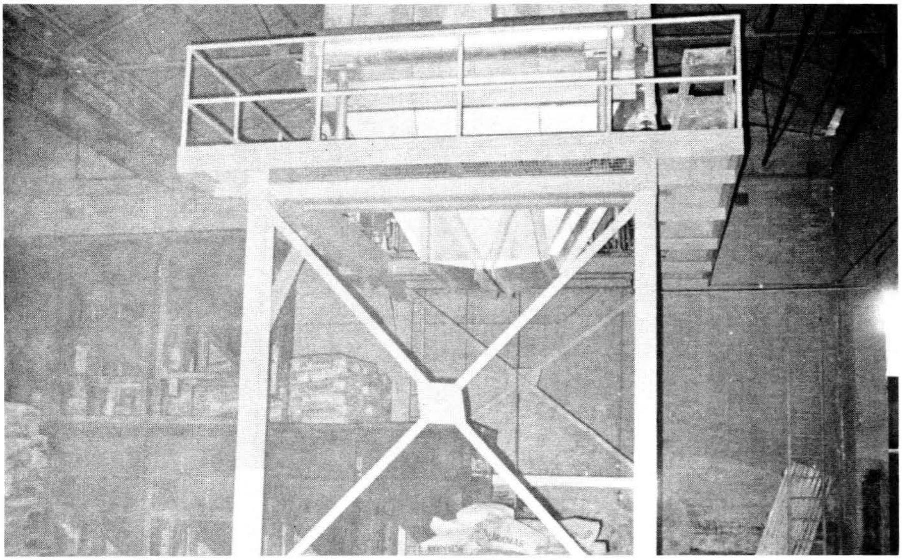


Figure 10. Many customers use fertilizer in bulk. The fertilizer is loaded into the customer's vehicle with a bulk loader such as this one. Note overhead conveyor for fertilizers.

Figure 11. Much of the fertilizer is picked up by the customer to reduce his freight and handling cost.

Figure 12. Fertilizers should be applied according to recommendations based on soil test and plant analysis. Care should be exercised in placement to prevent "burning" or damage to germinating seed and young plants.

The grower must decide how much fertilizer to apply, what analysis and ratio to apply, and how it should be applied. For the most efficient use of the fertilizer, soil samples should be taken and analyzed[6] to determine the fertilizer ratio and analysis and the amount of fertilizer needed. Additional information may be obtained by having plant tissue analyzed. Recommendations for fertilizer use based upon soil and/or plant analysis should be followed for best results.

The primary reason for using fertilizers is to supply plant food for the nutritive needs of the plant. Fertilizers will not compensate for the selection of poor crop varieties, inadequate disease and insect control, poor weed control, low or excessive soil moisture, or other poor management practices. However, when used properly, increased crop yields may be expected.

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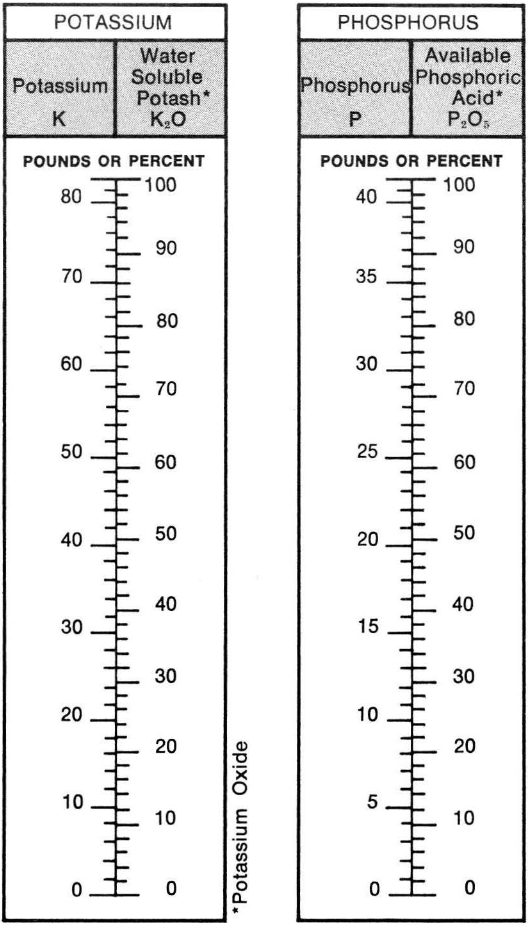
[6]For information on soil analysis see: McCall, W. W., **Have Your Soil Tested** (Univ. of Hawaii Coop. Ext. Ser. Circ. 437, 1969); McCall, W. W., **Take Good Soil Samples for Fertility Recommendations** (Univ. of Hawaii Coop. Ext. Ser. Circ. 428, 1968); and McCall, W. W., **How to Interpret Your Soil Test Results** (Univ. of Hawaii Coop. Ext. Ser. Circ. 432, 1969).

Table 2. Fertilizer Conversion Scales



*Potassium Oxide

*Phosphorus Pentoxide

$K \times 1.20 = K_2O$
$K_2O \times 0.83 = K$

$P \times 2.29 = P_2O_5$
$P_2O_5 \times 0.44 = P$

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